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NEGATIVE CORRELATION BETWEEN POLAR CAP VISUAL AURORA AND MAGNETIC ACTIVITY

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ABSTRACT

An investigation has been made of the relationship between the local (K) and planetary (K_p) magnetic activity and the occurrence of visual auroras inside the auroral zone. It is found that the visual aurora above geomagnetic latitude 80^o is negatively correlated with the K and K_p magnetic indices, whereas nearer to the auroral zone the correlation is positive. The relationship in the region 75-80^o latitude is more complicated and of a transitional nature.

Introduction

A number of investigations, including those by Gartlein (1944), Heppner (1954) and Davis (1962b), have shown a close association between the occurrence of visual aurora and local magnetic disturbance at and outside the auroral zone. On the other hand others, particularly Feldstein (1959) and Akasofu (1963) have indicated that no association or an inverse relationship may exist between the visual aurora and magnetic disturbance well inside the auroral zone. This paper reports a further investigation of the degree of association between the occurrence of visual auroral forms and magnetic activity inside the northern auroral zone.

Relationships between visual aurora and magnetic disturbance near the auroral zone

From a study of the alignments and apparent motions of visual auroras and of the direction of the horizontal component of local magnetic disturbance, Davis and Kimball (1962) found a strong tendency for perpendicularity between the direction of horizontal disturbance and the direction of alignment of nearby auroral forms. Further, it was found that the direction of overhead ionospheric current causing the local magnetic disturbance was usually opposite to that of the observed auroral motion. Such observations and others previously cited suggest a rather close association between the visual aurora and ionospheric current at the auroral zone.

Diagrams given by Davis (1962a, Figures 12 and 13) indicate that the occurrence or incidence of visual aurora at the auroral zone increases with bay-like disturbances of the horizontal component such that the greatest incidence tends to remain at the auroral zone irrespective of the strength or direction of the auroral electrojet. However, as the local magnetic disturbance increases, the aurora becomes more distributed in latitude; both the north and south limits of the display move in opposite directions away from the auroral zone as is shown in Figure 1. Akasofu and Chapman (1962) have shown that during those intervals of magnetic storms in which Dst is large, the region where the aurora occurs moves equatorward; that is, both the northern and the southern limits of the display shift equatorward. Thus it appears that near the auroral zone two separate relationships exist between the spatial distribution of the visual aurora and magnetic disturbance:

(1) the meridional extent of the display becomes larger concurrently with increase in the magnitude of the auroral electrojet, and

(2) the position of the longitudinal strip along which the auroral display occurs shifts equatorward as Dst becomes very large.

<u>Relationships between the visual aurora and magnetic disturbance inside the auroral zone</u>

Among the questions which may be asked regarding the polar cap aurora are: (1) What is the relationship between the visual aurora and the local magnetic activity?, and (2) What is the relationship of the visual aurora to global magnetic activity? Before entering into these questions it is well to discuss the measures of auroral and magnetic activity to be used.

The index of visual aurora activity used here is one devised to make use of direct scalings of all-sky camera films and of published Ascaplots (Annals of IGY, Vol. XX, Part I) which are also derived from all-sky films. This index is a form of percentage hourly occurrence in which those hours during which auroral forms are observed are weighted according to the latitudinal extent of sky coverage by the auroral forms. Observations are made only over that region within 200 km of each observing location. Only dark periods with satisfactory observing conditions are used to compile the auroral index. The index refers to the occurrence of distinct visible auroral forms, as distinguished from widespread glows which because of their uniformity or low brightness are not readily detected on the all-sky film. The numerical values of the auroral index given in the following text and diagrams are approximately equal to percentage values; that is, they indicate approximately the percentage of observing hours during which aurora was seen over the station. No attempts should be made to relate these values to the particle fluxes causing the aurora.

An index of local magnetic activity is the 3-hour index K_k, the magnitude of which is related to the range of the maximum magnetic variation during a 3-hour interval at the particular observing station k. The 3-hour planetary magnetic index K_p is compiled from the K_k values obtained from a distribution of individual stations. Since the K-index scales are non-linear, it is convenient for some purposes to convert to the linear amplitude scales a_k or a_p (Bartels, Romana and Veldkamp, 1962). In making use of these measures of magnetic activity it must be remembered that they refer to the range of magnetic field variation during a given time interval and do not necessarily describe the total distortion to the quiet geomagnetic field.

It is of interest to examine the relationship between the local magnetic activity well inside the auroral zone with the planetary activity indices K_p and a_p. For this purpose, three stations are chosen: Thule at geomagnetic latitude 88°N is nearly at the geomagnetic pole; Godhavn at 80°N is approximately midway between the pole and the auroral zone; and College, geomagnetic latitude $64\frac{1}{2}^{\circ}$, is just outside the auroral zone. Tables I and II indicate the relationship between the local K-indices and the planetary indices for Thule and Godhavn, respectively. The same data and similar data from College are converted to linear amplitude values a_k and a_p to allow forming of averages. These results are plotted in Figure 2. It is evident from Tables I and II and Figure 2 that the local K-indices and the derived average amplitude values a_k increase with increasing planetary activity. The rate of increase is greater at the auroral zone than inside; however, for each of the stations; College, Godhavn and Thule; the average amplitude $\bar{a}_k$ increases at a greater rate than the planetary index a_p.

The diurnal variations of the average linear amplitude indices $\bar{a}_k$ at College, Godhavn, and Thule are shown in Figures 3A, B and C, respectively, together with similar plots of the auroral occurrence index at each station. All auroral data used here result from the 1957-58 observing season except that 1958-59 observations are included with the Thule data in order to build up a better sample distribution for that station. Magnetic data from the period January 1 - June 30, 1958 are used to compile Figures 3A, B, C; this was a period of high magnetic and auroral activity.

From Figure 3A it is seen that the maxima of the auroral and local magnetic activity occur at the same time at College, near the auroral zone. Just the opposite occurs at Thule, near the geomagnetic pole; with the two diurnal variation curves for that station (Figure 3C) being out of phase by almost one-half day. At a station midway between the auroral zone and the pole, Godhavn (Figure 3B), much of the observed auroral activity occurs during a period of the day when the local magnetic activity is low, but then the auroral activity increases with increasing magnetic activity and reaches a peak a few hours before the peak in magnetic activity.

The relationship of the visual auroral occurrence at these three stations to the planetary index K_p is shown in Figure 4 by using data from the same period as in Figure 3. As is expected, Figure 4 shows that the visual auroral activity at College, near the auroral zone, increases with increasing K_p. On the other hand, Thule, located near the geomagnetic pole, shows a decrease in the occurrence of visual auroras as K_p increases. Godhavn, located midway between the pole and the auroral zone, shows a more complex relationship.

The auroral data of Figure 4 are plotted again in Figure 5, now against the local K-indices. Except for a more limited range of K-values for which sufficient data are available, the curves of Figure 5 are nearly identical with those of Figure 4. Thus the above discussion of Figure 4 can be applied to Figure 5 by replacing K_p with K_k in that discussion. The dependence upon local time of the aurora and local magnetic activity at Thule could create by itself the negative correlation observed at that station. This possibility was investigated by dividing the observations made during the 06-09 hour U.T. interval into two groups according to the level of local magnetic activity. The auroral index for the hours when K_{Thule} = 0, 1, 2, was 82; an auroral index value of 58 occurred for the group in which K_{Thule} = 3, 4, 5. Thus the negative correlation between aurora and local magnetic activity at Thule is independent of a local time effect.

More complete information regarding the occurrence of visual aurora as a function of geomagnetic latitude and planetary magnetic activity is presented in Figures 6 and 7. The occurrence of visual aurora at Baker Lake, see Figure 7, is relatively constant at all levels of magnetic activity. Below the latitude of Baker Lake there exists a positive correlation between the visual aurora and the planetary magnetic activity. At latitudes above 80^{O}N a negative correlation exists between the visual aurora and the magnetic activity.

Discussion and Conclusions

The data presented here show conclusively that at very high geomagnetic latitudes the occurrence of structured visual aurora decreases as local and planetary magnetic activity increases. The demarcation between this polar cap region and the lower-latitude region where the occurrence of visual aurora correlates positively with the local and planetary magnetic activity occurs at 75^{O} - 80^{O} geomagnetic latitude.

This 75-80^{O} region also serves as an approximate boundary across which appear several differences in the morphological features of the visual aurora: (1) The polar cap auroras are comparatively weak and shortlived. (2) They tend to exhibit more ray structure than those auroras occurring near the auroral zone. (3) The auroras at the auroral zone tend to be aligned in the east-west direction, whereas the polar cap auroras vary in orientation such that the average orientation is in the direction approximately along the 10 - 22^h meridian. (4) Motions of irregularities along auroral forms are pronounced at the auroral zone but much less obvious in the polar cap region. (5) The diurnal behavior of the polar cap aurora differs from that at the auroral zone.

These morphological differences and the opposite correlation between visual aurora and magnetic activity across the 75 - 80^o latitude boundary suggest the possibility of a difference in the origin of the auroras occurring on the two sides of the boundary. A projection of the 75 - 80^o boundary along a dipole geomagnetic field falls at a distance of 15 to 35 earth radii. Results from Explorer X (Heppner, et al, 1963) indicate that the dark-side magnetosphere boundary occurs in or beyond this distance range. If the projection of the 75 - 80^o boundary coincides with the magnetosphere boundary near or above the equatorial plane, the polar cap auroras may result from particles penetrating the magnetosphere away from the equatorial plane and passing directly to the polar atmosphere. During those times when particles cross the magnetosphere boundary, it may be necessary for the local geomagnetic field to have a component normal to the boundary and thus not be completely confined by it.

An alternate interpretation of the observations involves the supposition that both the polar cap and auroral zone visual auroras are caused by completely trapped primary particles. The paths of the primaries causing the polar cap visual aurora are then largely in regions of low magnetic field strength and therefore easily affected by transients arising from variation of the solar wind strength. This factor could explain the negative correlation between the occurrence of the polar cap visual forms and magnetic activity.

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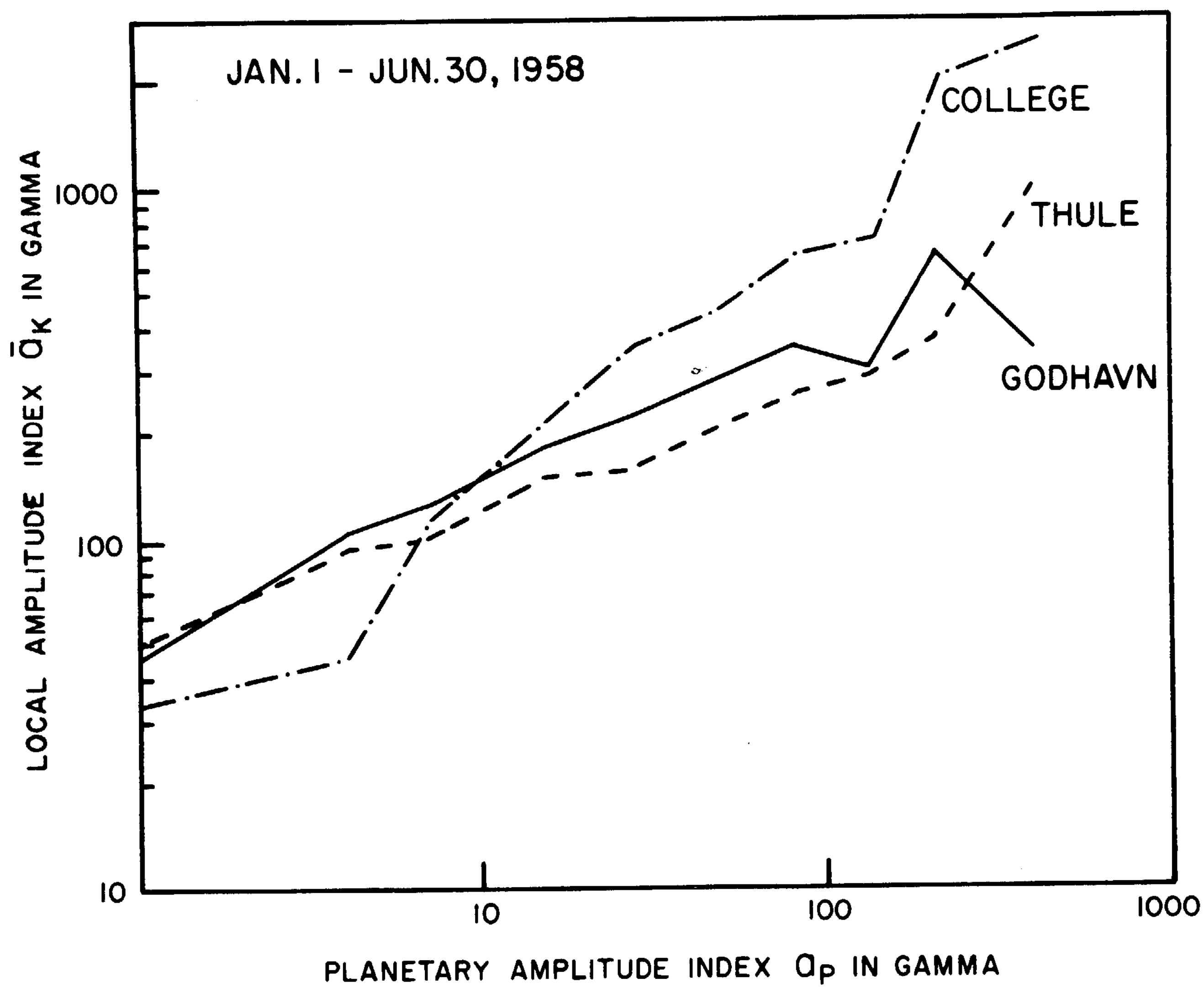
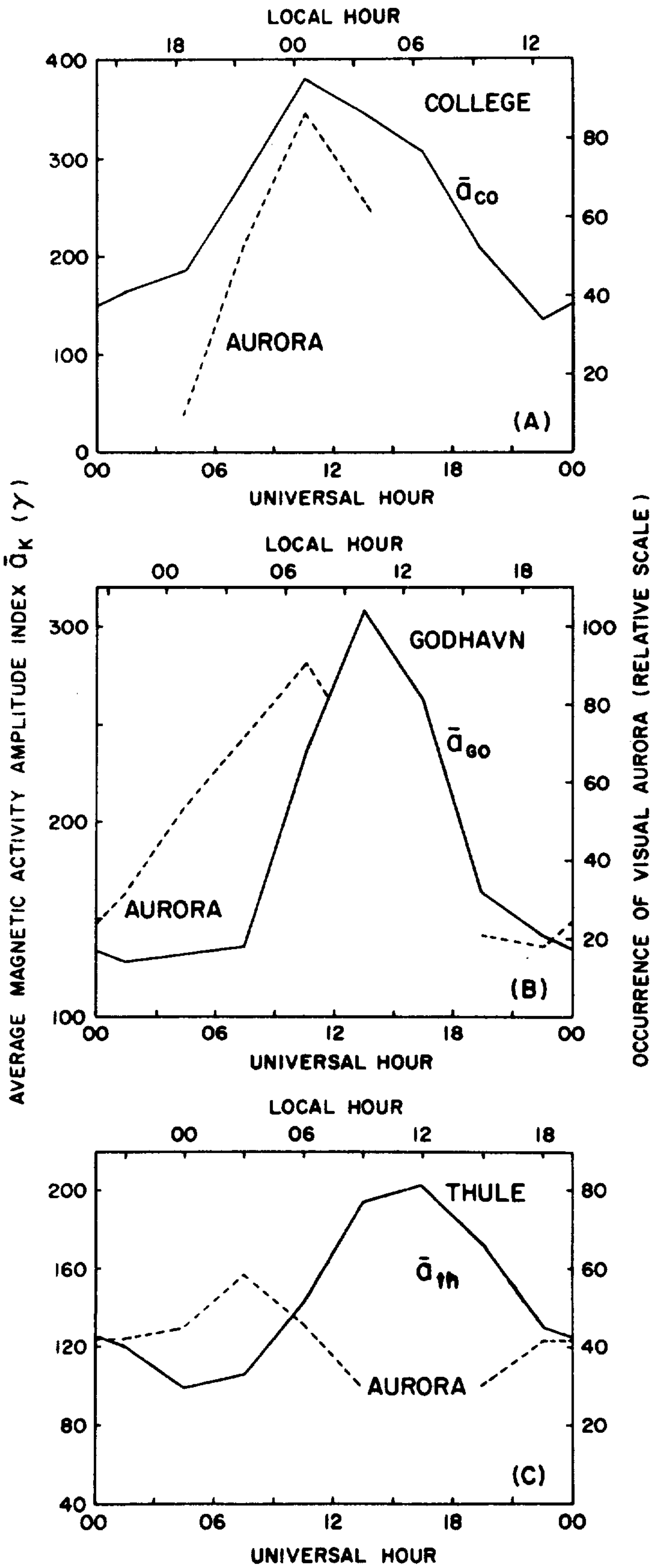

JAN. 1 - JUN. 30, 1958
COLLEGE
THULE
GODHAVN
1000
100
10
10
100
1000
LOCAL AMPLITUDE INDEX $\bar{a}_K$ IN GAMMA
PLANETARY AMPLITUDE INDEX a_p IN GAMMA

Figure 2



LOCAL HOUR
18
00
06
12
400
300
200
100
0
COLLEGE
80
60
40
20
$\bar{a}_{co}$
AURORA
(A)
00
06
12
18
00
UNIVERSAL HOUR
AVERAGE MAGNETIC ACTIVITY AMPLITUDE INDEX $\bar{a}_K$ (γ)
OCCURRENCE OF VISUAL AURORA (RELATIVE SCALE)
LOCAL HOUR
00
06
12
18
300
200
100
GODHAVN
100
80
60
40
20
$\bar{a}_{GO}$
AURORA
(B)
00
06
12
18
00
UNIVERSAL HOUR
LOCAL HOUR
00
06
12
18
200
160
120
80
40
THULE
80
60
40
20
$\bar{a}_{th}$
AURORA
(C)
00
06
12
18
00
UNIVERSAL HOUR

Figure 3

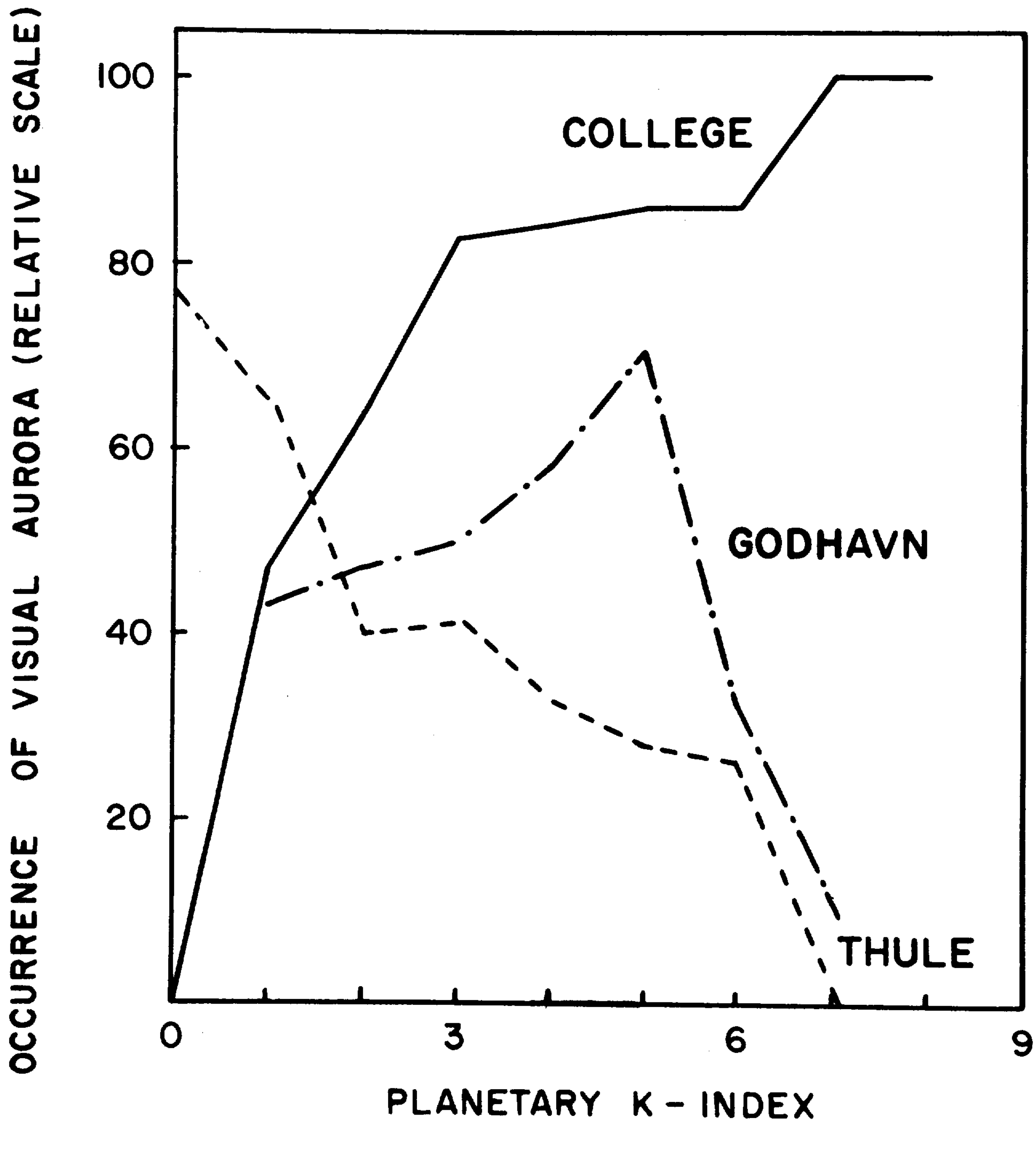

OCCURRENCE OF VISUAL AURORA (RELATIVE SCALE)
100
80
60
40
20
COLLEGE
GODHAVN
THULE
0
3
6
9
PLANETARY K - INDEX

Figure 4

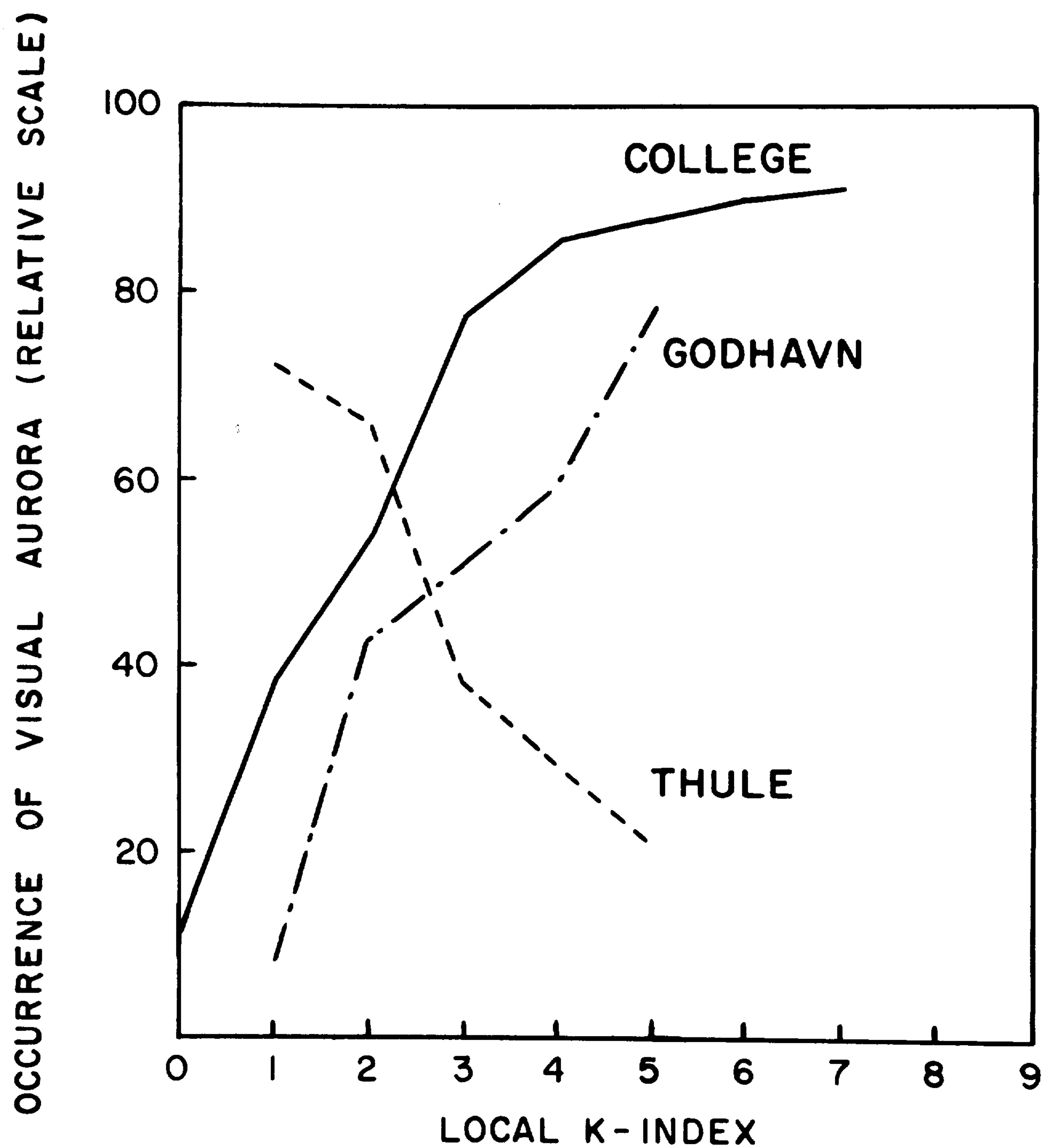

OCCURRENCE OF VISUAL AURORA (RELATIVE SCALE)
100
80
60
40
20
COLLEGE
GODHAVN
THULE
0
1
2
3
4
5
6
7
8
9
LOCAL K-INDEX

Figure 5

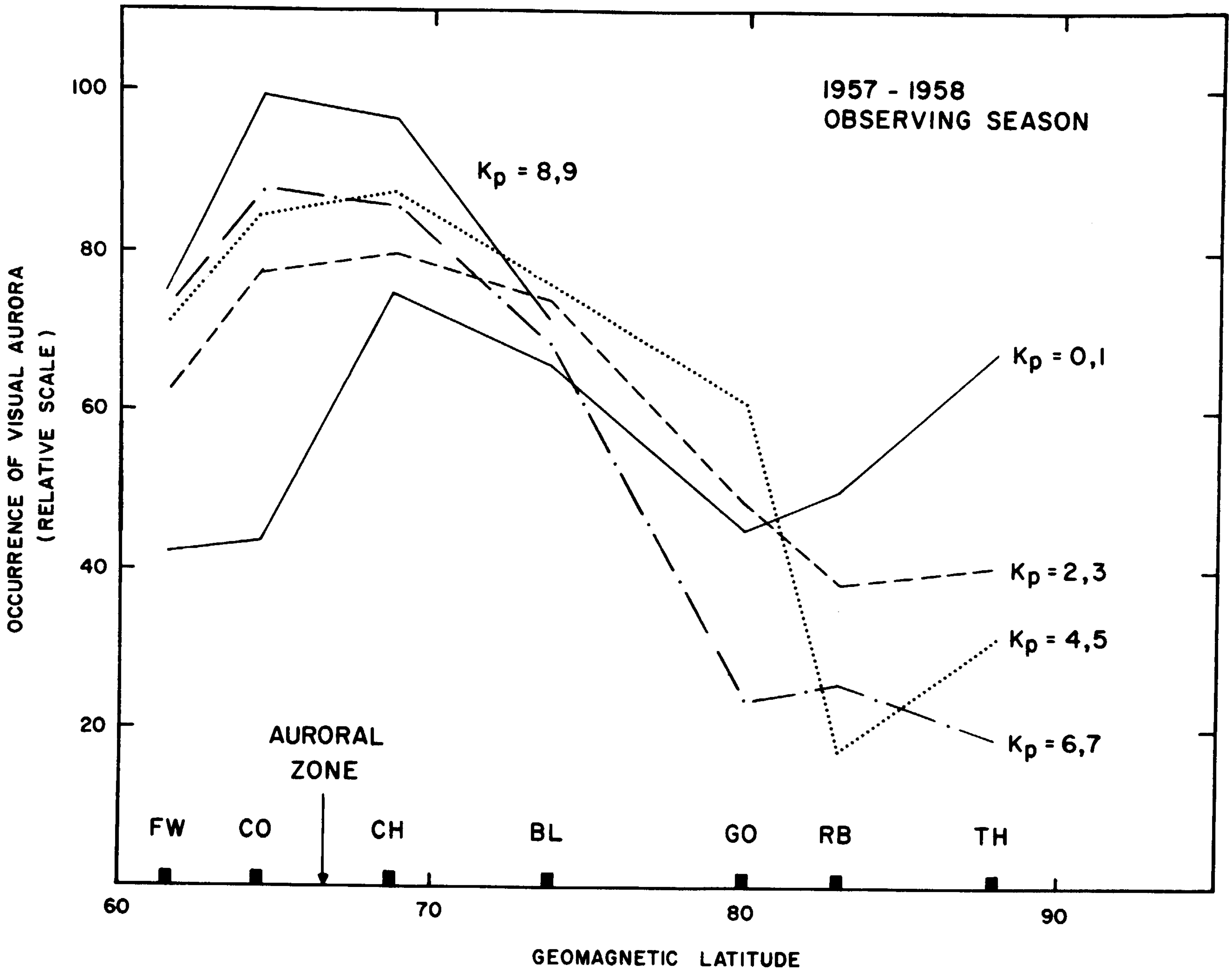

1957 - 1958
OBSERVING SEASON
$K_p = 8,9$
$K_p = 0,1$
$K_p = 2,3$
$K_p = 4,5$
$K_p = 6,7$
OCCURRENCE OF VISUAL AURORA
(RELATIVE SCALE)
100
80
60
40
20
AURORAL
ZONE
FW
CO
CH
BL
GO
RB
TH
60
70
80
90
GEOMAGNETIC LATITUDE

Figure 6

TABLE TITLES

Table I: The distribution of Thule K-index values at the various levels of planetary activity K_p for the period January 1 - June 30, 1958.

TABLE II: The distribution of Godhavn K-index values at the various levels of planetary activity K_p for the period January 1 - June 30, 1958.

TABLE I. The distribution of Thule K-index values at the various levels of planetary activity for the period January 1 - June 30, 1958.

$K_p \backslash K_{TH}$	0	1	2	3	4	5	6	7	8	9
0		6	7	9	5					
1		14	53	52	60	34	8	1		
2		1	37	102	77	43	10	1		
3			10	70	137	105	34	7		
4			2	39	148	124	32	7		
5					36	64	28	5		
6					7	32	10	5	2	
7					1	6	1	3		
8						3	5	1	1	
9								1		1

TABLE II. The distribution of Godhavn K-index values at the various levels of planetary activity K_p for the period of January 1 - June 30, 1958.

$K_p \backslash K_{GO}$	0	1	2	3	4	5	6	7	8	9
0		9	15	3						
1		30	68	77	40	9				
2		6	83	108	57	21	1			
3			41	160	105	46	22	1		
4			8	109	131	72	25	1		
5				18	55	41	15	2		
6				2	12	23	6	2		1
7				1	4	4	2			
8				1	1	5	2			1
9						1				

FIGURE TITLES

Figure No.	Title
1	Position of north and south boundaries of auroral displays over Alaska as a function of magnetic disturbance during the displays of February 12 - 26, 1958.
2	Plots of three-hour average amplitude indices $\bar{a}_k$ versus the three-hour planetary amplitude index a_p; log scale.
3	The diurnal variation of the three-hour amplitude index of planetary activity a_k and of the occurrence of visual aurora at a) College, b) Godhavn, and c) Thule.
4	The occurrence of visual aurora plotted as a function of the planetary magnetic activity index K_p.
5	The occurrence of visual aurora plotted as a function of the local magnetic activity index K_k.
6	The occurrence of visual aurora plotted as a function of geomagnetic latitude for various levels of planetary magnetic activity. Observations come from Farewell, Alaska (FW), College, Alaska (CO), Churchill, Canada (CH), Baker Lake, Canada (BL), Godhavn, Greenland (GO), Resolute Bay, Canada (RB), and Thule, Greenland (TH).
7	Levels of occurrence of visual aurora versus planetary magnetic activity at seven latitude positions. Observations are from the stations listed in the upper right.

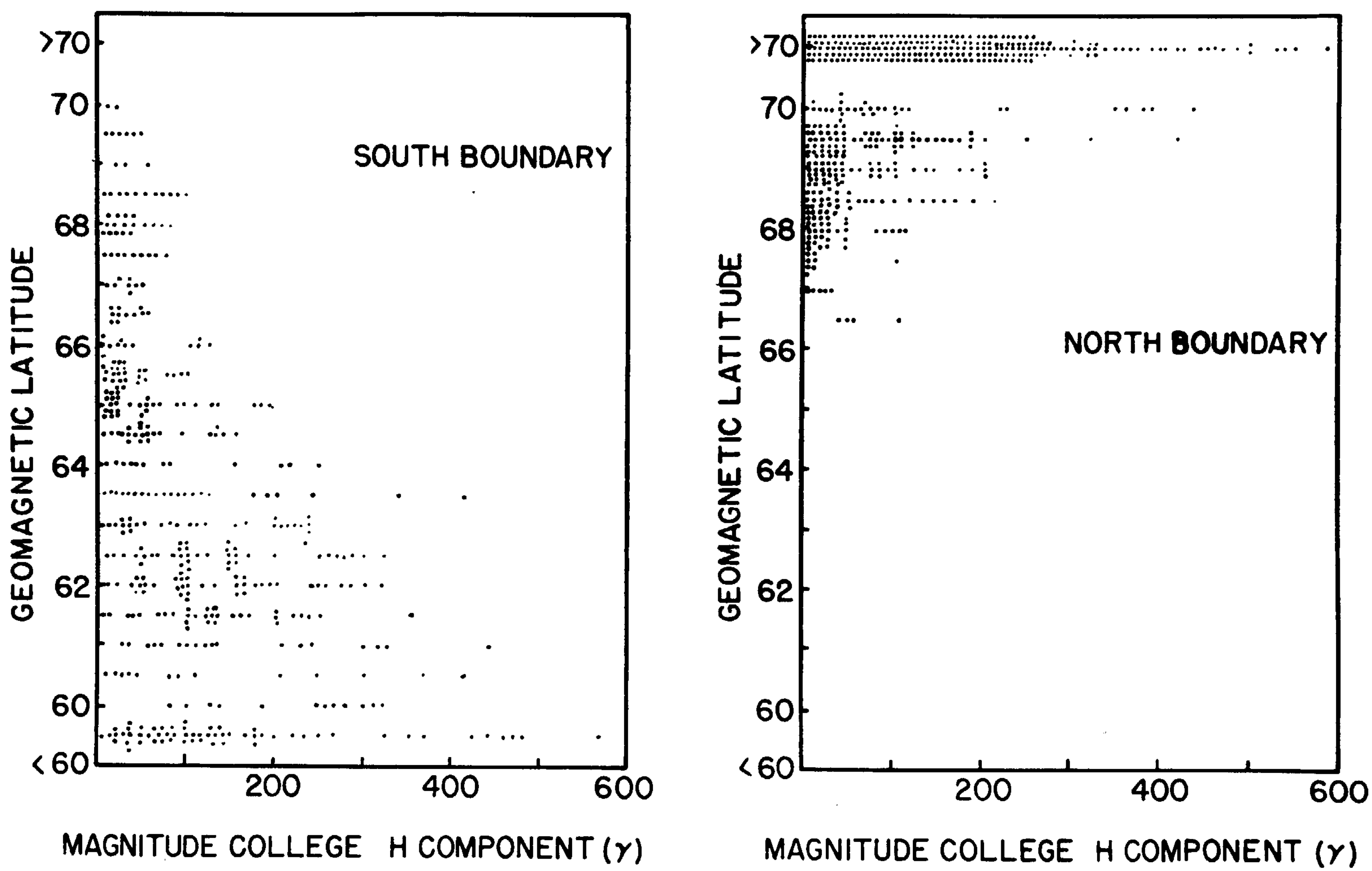

SOUTH BOUNDARY
GEOMAGNETIC LATITUDE
>70
70
68
66
64
62
60
<60
200
400
600
MAGNITUDE COLLEGE H COMPONENT (γ)
NORTH BOUNDARY
GEOMAGNETIC LATITUDE
>70
70
68
66
64
62
60
<60
200
400
600
MAGNITUDE COLLEGE H COMPONENT (γ)

Figure 1

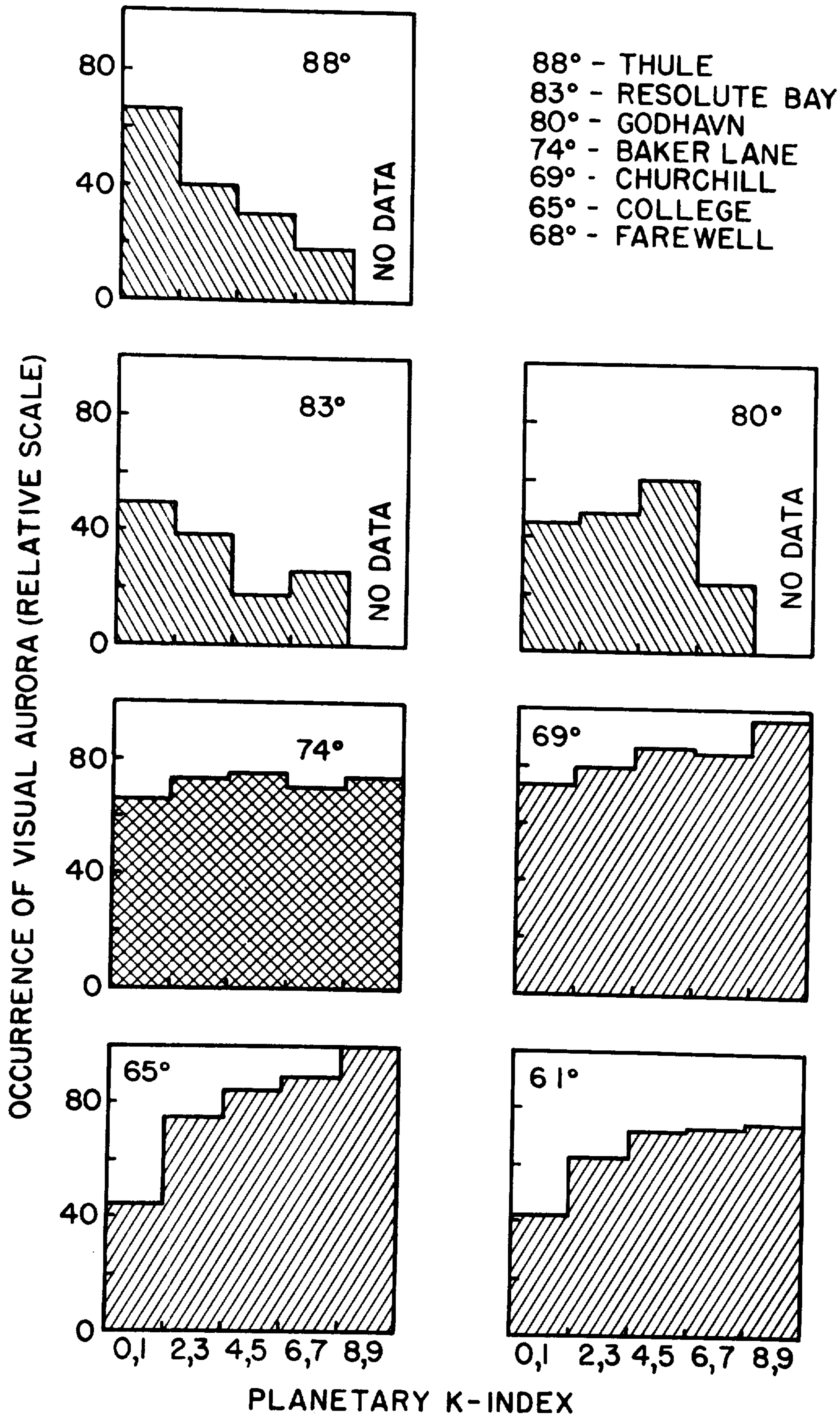

88° - THULE
83° - RESOLUTE BAY
80° - GODHAVN
74° - BAKER LANE
69° - CHURCHILL
65° - COLLEGE
68° - FAREWELL
OCCURRENCE OF VISUAL AURORA (RELATIVE SCALE)
88°
83°
80°
74°
69°
65°
61°
NO DATA
NO DATA
NO DATA
0
40
80
0,1
2,3
4,5
6,7
8,9
PLANETARY K-INDEX

Figure 7